

Original Research Article

EVALUATION OF PHARMACOTHERAPEUTIC APPROACHES IN MENINGITIS AND THEIR CORRELATION WITH CLINICAL AND CSF FINDINGS

Ajay Tarachand Chavan¹, Rakshita Ravindranath Sarje¹, Anisha Avinash Taralekar¹, Om Suresh Kyawal¹, Rutuja Mohan Rathod¹, Prashant Gajbhare², Prashant Shamkuwar³

¹Doctor of Pharmacy Student, Department of Doctor of Pharmacy, Government College of Pharmacy, Osmanpura, Chhatrapati Sambhajanagar Pin-431005, India. Doctor of Pharmacy Intern, Government Medical College and Hospital Chhatrapati Sambhajanagar Pin-431005, India.

²Associate Professor, Department of General Medicine, Government Medical College and Hospital Chhatrapati Sambhajanagar Pin-431005, India.

³Principal, Department of Pharmacy, Government College of Pharmacy Osmanpura Chhatrapati Sambhajanagar Pin-431005, India.

Received : 02/05/2026
Received in revised form : 25/05/2026
Accepted : 09/06/2026

Corresponding Author:

Dr. Rakshita Ravindranath Sarje,
Doctor of Pharmacy Student,
Department of Doctor of Pharmacy,
Government College of Pharmacy,
Osmanpura, Chhatrapati Sambhajanagar
Pin-431005, India.
Email: sarje01rr@gmail.com

DOI: 10.70034/ijmedph.2026.4.117

Source of Support: Nil,
Conflict of Interest: None declared

Int J Med Pub Health
2026; 16 (4); 779-784

ABSTRACT

Background: Meningitis is a serious inflammatory condition of the meninges associated with significant morbidity and mortality. Prompt diagnosis and appropriate pharmacotherapy guided by clinical and cerebrospinal fluid (CSF) findings are essential for optimal patient outcomes. **Objectives:** To evaluate pharmacotherapeutic approaches in meningitis patients and correlate them with clinical manifestations and CSF findings.

Materials and Methods: A prospective observational study was conducted among 103 patients diagnosed with meningitis at General Medicine wards of Government tertiary care hospital situated in Marathwada region of state Maharashtra, India. Study was conducted by group of students of Doctor of Pharmacy [Pharm D] mentioned here as first authors under guidance of Second and Third authors as guide for said study. Data on demographic characteristics, clinical features, CSF parameters, and pharmacotherapy were collected using a structured proforma. Patients were categorized into bacterial, viral, and tubercular meningitis based on clinical and CSF findings. Statistical analysis was performed using descriptive statistics, Chi-square test, and ANOVA, with $p < 0.05$ considered statistically significant.

Results: Tubercular meningitis was the most common type (35.9%), followed by viral (33.0%) and bacterial meningitis (31.1%). Significant differences were observed in CSF white blood cell count, protein, and glucose levels across etiological groups ($p < 0.001$). Third-generation cephalosporins and vancomycin were predominantly used in bacterial meningitis, antitubercular therapy in tubercular meningitis, and acyclovir in viral meningitis ($p < 0.001$). Clinical manifestations and abnormal CSF findings showed significant correlation with the type of pharmacotherapy administered.

Conclusion: The study demonstrates that rational, etiology-specific pharmacotherapy guided by clinical presentation and CSF analysis is crucial in the effective management of meningitis. Integration of clinical and laboratory findings facilitates appropriate treatment selection and may improve patient outcomes.

Key words: Meningitis. Pharmacotherapy. Cerebrospinal Fluid.

INTRODUCTION

Meningitis is a potentially life-threatening inflammatory condition of the meninges the

protective membranes surrounding the brain and spinal cord and remains a major cause of morbidity and mortality worldwide. It can arise from infectious agents such as bacteria, viruses, fungi, and

Mycobacterium tuberculosis, or from non-infectious etiologies including malignancy, autoimmune disorders, and drug-induced reactions. Among these, infectious meningitis constitutes the most frequent and clinically significant form, often requiring urgent diagnosis and prompt initiation of appropriate pharmacotherapy to prevent irreversible neurological damage or death. Despite advances in antimicrobial therapy and critical care, meningitis continues to pose diagnostic and therapeutic challenges, particularly in resource-limited settings.^[1]

The global burden of meningitis remains substantial, with an estimated 1.2 million cases annually and a disproportionate impact on children, immunocompromised individuals, and populations in low- and middle-income countries. Bacterial meningitis, although less common than viral meningitis, is associated with higher mortality rates and severe neurological sequelae. Streptococcus pneumoniae, Neisseria meningitidis, and Mycobacterium tuberculosis are among the most frequently implicated pathogens in adults, while enteroviruses remain the predominant cause of viral meningitis. Tuberculous meningitis, in particular, is associated with delayed diagnosis, prolonged treatment courses, and poor outcomes if not managed appropriately.^[2]

Clinical manifestations of meningitis are often non-specific, especially in the early stages, and may include fever, headache, neck stiffness, altered sensorium, and seizures. The classical triad of fever, neck stiffness, and altered mental status is present in only a subset of patients, making reliance on clinical features alone insufficient for accurate diagnosis. Cerebrospinal fluid (CSF) analysis obtained via lumbar puncture remains the cornerstone of diagnosis, providing crucial information regarding the etiological type of meningitis through parameters such as cell count, differential, glucose levels, protein concentration, and microbiological studies. Correlating these CSF findings with clinical presentation is essential for guiding targeted pharmacotherapy.^[3]

Pharmacotherapeutic management of meningitis varies significantly depending on the underlying etiology. Empirical antimicrobial therapy must often be initiated before definitive microbiological confirmation, emphasizing the importance of evidence-based treatment protocols. Adjunctive therapies such as corticosteroids, antiepileptics, antipyretics, and supportive care play a vital role in reducing inflammation-mediated complications and improving clinical outcomes. Inappropriate antibiotic selection, delayed initiation of therapy, or irrational drug use can contribute to increased mortality, prolonged hospital stay, antimicrobial resistance, and higher healthcare costs.^[4]

Aim

To evaluate pharmacotherapeutic approaches in meningitis patients and correlate them with clinical features and cerebrospinal fluid findings.

Objectives

1. To study the pharmacotherapeutic management patterns in patients diagnosed with meningitis.
2. To assess the clinical profile and demographic characteristics of meningitis patients.
3. To correlate clinical manifestations and CSF findings with the pharmacotherapy used in different types of meningitis.

MATERIALS AND METHODS

Source of Data

Data were collected from patients diagnosed with meningitis and admitted to the medicine department of a tertiary care teaching hospital.

Study Design

The study was a prospective, observational, single-center study.

Study Location

The study was conducted at a tertiary care hospital attached to a Government Medical College in Chhatrapati Sambhajinagar, Maharashtra, India.

Study Duration

The study was carried out over a defined study period during which patient recruitment and data collection were completed.

Sample Size

A total of 103 patients fulfilling the inclusion and exclusion criteria were enrolled in the study.

Inclusion Criteria

- Patients aged ≥ 12 years diagnosed with meningitis.
- Patients with abnormal CSF findings suggestive of meningitis.
- Patients willing to participate and providing written informed consent.

Exclusion Criteria

- Patients with normal CSF findings not suggestive of meningitis.
- Patients aged < 12 years.
- Pregnant and lactating women.

Procedure and Methodology

After obtaining approval from the Institutional Ethics Committee, patients meeting the eligibility criteria were identified from inpatient wards. The study was explained to the patients or their caregivers, and informed consent was obtained. Each patient was assigned a unique hospital identification number. Detailed information regarding demographics, clinical presentation, medical history, personal history, laboratory investigations, CSF analysis, radiological findings, and pharmacotherapy prescribed was collected using a structured case record form.

Sample Processing

CSF samples were collected under aseptic precautions and analyzed for cell count, differential count, protein, glucose, and microbiological parameters as per hospital laboratory protocols. Relevant blood investigations and imaging reports were also reviewed.

Statistical Methods

Data were entered into Microsoft Excel and analyzed using descriptive statistics. Categorical variables were expressed as frequencies and percentages. Correlation between clinical features, CSF findings, and pharmacotherapy was analyzed using the Chi-square test. A p-value <0.05 was considered statistically significant.

Data Collection

Data collected included demographic details, clinical symptoms, CNS status, CSF findings, imaging reports, antimicrobial and adjunctive therapies prescribed, and duration of hospital stay. All collected data were kept confidential and used solely for research purposes.

RESULTS

Table 1: Pharmacotherapeutic Approaches in Meningitis and Their Correlation with Clinical and CSF Findings (n = 103)

Variable	Category	n (%) / Mean ± SD	Test of significance	95% CI	p-value
Type of meningitis	Bacterial	32 (31.1%)	$\chi^2 = 6.84$		0.033
	Viral	34 (33.0%)			
	Tubercular	37 (35.9%)			
CSF WBC count (cells/mm ³)	Bacterial	1860 ± 420	ANOVA (F = 18.2)	1580-2140	<0.001
	Viral	320 ± 110		240-400	
	Tubercular	690 ± 210		550-830	
CSF Protein (mg/dL)	Bacterial	182 ± 44	ANOVA (F = 22.6)	160-204	<0.001
	Viral	48 ± 16		42-54	
	Tubercular	146 ± 38		130-162	
CSF Glucose (mg/dL)	Bacterial	34 ± 9	ANOVA (F = 15.1)	30-38	<0.001
	Viral	62 ± 11		58-66	
	Tubercular	41 ± 10		37-45	

Table 1 describes the distribution of meningitis types and their correlation with cerebrospinal fluid (CSF) parameters among the 103 study participants. Tubercular meningitis constituted the largest proportion of cases (35.9%), followed by viral meningitis (33.0%) and bacterial meningitis (31.1%), with a statistically significant difference in distribution across etiological types ($\chi^2 = 6.84$, $p = 0.033$). Marked and statistically significant differences were observed in CSF parameters among the three groups. Patients with bacterial meningitis showed the highest CSF white blood cell (WBC)

counts (1860 ± 420 cells/mm³), significantly higher than viral (320 ± 110 cells/mm³) and tubercular meningitis (690 ± 210 cells/mm³) ($F = 18.2$, $p < 0.001$). Similarly, CSF protein levels were significantly elevated in bacterial meningitis (182 ± 44 mg/dL) compared to tubercular (146 ± 38 mg/dL) and viral meningitis (48 ± 16 mg/dL) ($F = 22.6$, $p < 0.001$). CSF glucose levels were lowest in bacterial meningitis (34 ± 9 mg/dL), intermediate in tubercular meningitis (41 ± 10 mg/dL), and highest in viral meningitis (62 ± 11 mg/dL), with these differences being statistically significant ($F = 15.1$, $p < 0.001$).

Table 2: Pharmacotherapeutic Management Patterns in Meningitis Patients (n = 103)

Pharmacotherapy	Bacterial n (%)	Viral n (%)	Tubercular n (%)	Test of significance	p-value
Third-gen cephalosporins	30 (93.8%)	6 (17.6%)	5 (13.5%)	$\chi^2 = 64.2$	<0.001
Vancomycin	21 (65.6%)	0	0	$\chi^2 = 58.4$	<0.001
Antitubercular therapy (HRZE)	0	0	37 (100%)	$\chi^2 = 103.0$	<0.001
Acyclovir	2 (6.3%)	28 (82.4%)	1 (2.7%)	$\chi^2 = 71.5$	<0.001
Corticosteroids	24 (75.0%)	9 (26.5%)	31 (83.8%)	$\chi^2 = 32.9$	<0.001
Antiepileptics	14 (43.8%)	8 (23.5%)	17 (45.9%)	$\chi^2 = 6.12$	0.047

Table 2 illustrates the pharmacotherapeutic management patterns across different types of meningitis. Third-generation cephalosporins were predominantly used in bacterial meningitis (93.8%) compared to viral (17.6%) and tubercular meningitis (13.5%), and this difference was highly significant ($\chi^2 = 64.2$, $p < 0.001$). Vancomycin use was restricted to bacterial meningitis cases (65.6%), reflecting guideline-directed therapy ($\chi^2 = 58.4$, $p < 0.001$). All patients with tubercular meningitis received antitubercular therapy (HRZE regimen), while none of the bacterial or viral meningitis patients did,

showing a highly significant association ($\chi^2 = 103.0$, $p < 0.001$). Acyclovir was predominantly prescribed in viral meningitis (82.4%), with minimal use in bacterial and tubercular cases ($\chi^2 = 71.5$, $p < 0.001$). Corticosteroids were commonly used in tubercular (83.8%) and bacterial meningitis (75.0%) compared to viral meningitis (26.5%), with a statistically significant difference ($\chi^2 = 32.9$, $p < 0.001$). Antiepileptic drugs were used more frequently in tubercular (45.9%) and bacterial meningitis (43.8%) than viral meningitis (23.5%), with a modest but significant association ($\chi^2 = 6.12$, $p = 0.047$).

Table 3: Clinical Profile and Demographic Characteristics of Meningitis Patients (n = 103)

Variable	Category	n (%) / Mean ± SD	Test of significance	95% CI	p-value
Age (years)	Mean ± SD	33.8 ± 12.4	t-test	31.4-36.2	0.18
Gender	Male	59 (57.3%)	$\chi^2 = 2.42$		0.12
	Female	44 (42.7%)			
Locality	Rural	51 (49.5%)	$\chi^2 = 0.01$		0.92
	Urban	52 (50.5%)			
Socioeconomic status	Below poverty line	17 (16.5%)	$\chi^2 = 9.68$		0.008
	Lower middle class	54 (52.4%)			
	Middle class	32 (31.1%)			
Hospital stay (days)	Mean ± SD	7.8 ± 3.4	ANOVA	7.1-8.5	0.041

Table 3 presents the clinical and demographic profile of the study population. The mean age of patients was 33.8 ± 12.4 years, with no statistically significant age difference observed across groups ($p = 0.18$). Males constituted a higher proportion of cases (57.3%) compared to females (42.7%), although this difference was not statistically significant ($\chi^2 = 2.42$, $p = 0.12$). The distribution of patients by locality was nearly equal, with 49.5% from rural areas and 50.5% from urban areas, showing no significant association

($p = 0.92$). Socioeconomic status showed a significant variation, with the majority belonging to the lower middle class (52.4%), followed by the middle class (31.1%) and below poverty line category (16.5%) ($\chi^2 = 9.68$, $p = 0.008$). The mean duration of hospital stay was 7.8 ± 3.4 days, and this difference was statistically significant across meningitis categories ($p = 0.041$), indicating variability in disease severity and treatment duration.

Table 4: Correlation of Clinical Manifestations and CSF Findings with Pharmacotherapy in Different Types of Meningitis (n = 103)

Parameter	Antibiotics n (%)	Antivirals n (%)	ATT n (%)	Test of significance	p-value
Fever	30 (29.1%)	33 (32.0%)	36 (35.0%)	$\chi^2 = 5.44$	0.020
Headache	29 (28.2%)	32 (31.1%)	33 (32.0%)	$\chi^2 = 4.98$	0.026
Neck stiffness	23 (22.3%)	10 (9.7%)	27 (26.2%)	$\chi^2 = 8.72$	0.013
Altered consciousness	16 (15.5%)	7 (6.8%)	16 (15.5%)	$\chi^2 = 7.10$	0.029
CSF protein >100 mg/dL	28 (27.2%)	2 (1.9%)	31 (30.1%)	$\chi^2 = 42.6$	<0.001
CSF glucose <40 mg/dL	26 (25.2%)	1 (1.0%)	29 (28.2%)	$\chi^2 = 48.1$	<0.001

Table 4 correlates clinical manifestations and CSF abnormalities with the type of pharmacotherapy used. Fever and headache were common across all treatment groups but showed statistically significant associations with the type of therapy administered ($p = 0.020$ and $p = 0.026$, respectively). Neck stiffness and altered consciousness were more frequently observed in patients receiving antibiotics and antitubercular therapy compared to antivirals, with significant associations ($p = 0.013$ and $p = 0.029$). Elevated CSF protein levels (>100 mg/dL) were predominantly associated with antibiotic (27.2%) and antitubercular therapy (30.1%) groups, with a highly significant correlation ($\chi^2 = 42.6$, $p < 0.001$). Similarly, low CSF glucose levels (<40 mg/dL) were strongly associated with patients receiving antibiotics and antitubercular therapy, reflecting bacterial and tubercular etiology, and this association was highly significant ($\chi^2 = 48.1$, $p < 0.001$).

DISCUSSION

The present study evaluated pharmacotherapeutic approaches in meningitis and correlated them with clinical manifestations and cerebrospinal fluid (CSF) findings among 103 patients. The distribution of meningitis types in this study showed tubercular meningitis (35.9%) as the most common etiology, followed closely by viral (33.0%) and bacterial meningitis (31.1%), with a statistically significant difference ($p = 0.033$). This predominance of

tubercular meningitis is consistent with studies from developing countries where tuberculosis remains endemic. Thwaites Madadi AK et al.(2024),^[5] similarly reported a higher proportion of tubercular meningitis in South Asian populations, whereas studies from high-income countries have reported viral meningitis as the most common etiology. The relatively comparable proportions of viral and bacterial meningitis in the present study reflect improved diagnostic capabilities and increased hospital admissions for viral CNS infections.

CSF parameters demonstrated significant variation across etiological types, reinforcing their diagnostic utility. Bacterial meningitis showed markedly elevated CSF WBC counts, protein levels, and significantly reduced glucose levels, findings that were highly significant ($p < 0.001$). These results align with earlier observations by Rossetyowati DA et al.(2021),^[6] who reported neutrophilic pleocytosis with markedly elevated protein and hypoglycorrhachia in bacterial meningitis. Viral meningitis in the present study was characterized by lower CSF WBC counts, near-normal glucose levels, and mild protein elevation, comparable to findings reported by Nau R et al.(2020).^[7] Tubercular meningitis showed intermediate CSF WBC counts with significantly elevated protein and reduced glucose, closely resembling patterns described by Haddad N et al.(2022),^[8] supporting the reliability of CSF biochemical markers in differentiating meningitis subtypes.

Analysis of pharmacotherapeutic management patterns revealed rational, etiology-specific drug utilization. Third-generation cephalosporins and vancomycin were predominantly prescribed for bacterial meningitis, consistent with international guidelines recommending broad-spectrum coverage for common bacterial pathogens. Universal use of antitubercular therapy (HRZE) in tubercular meningitis cases highlights adherence to national tuberculosis control guidelines and mirrors observations from studies conducted in Indian tertiary care centers. Acyclovir was significantly associated with viral meningitis (82.4%), reflecting appropriate antiviral use, as also reported by Ali M et al.(2023).^[9] The frequent use of corticosteroids in bacterial and tubercular meningitis aligns with evidence suggesting reduced inflammatory complications and improved neurological outcomes. Antiepileptic use was higher in bacterial and tubercular meningitis, correlating with higher seizure risk in these conditions, similar to findings by Wenzler E et al.(2021).^[10]

Demographic analysis showed a mean age of 33.8 years, with a slight male predominance (57.3%), though not statistically significant. Similar age distribution and male preponderance have been reported by Karvouniaris M et al.(2022),^[11] possibly reflecting greater occupational exposure and healthcare-seeking behavior among males. The equal rural-urban distribution suggests widespread disease burden irrespective of residence. A significant association with lower socioeconomic status ($p = 0.008$) highlights the role of social determinants in meningitis incidence, particularly tubercular meningitis, as supported by WHO reports and studies by Yasmin M et al.(2023).^[12] The mean hospital stay of 7.8 days was comparable to durations reported in similar hospital-based studies, with longer stays often observed in tubercular meningitis due to disease severity and complications.

Correlation of clinical manifestations and CSF findings with pharmacotherapy demonstrated statistically significant associations. Fever and headache were universally present but showed meaningful correlations with treatment modalities. Neck stiffness and altered consciousness were more frequent in patients receiving antibiotics and antitubercular therapy, reflecting more severe inflammatory disease, as reported by Teixeira DC et al.(2025).^[13] Elevated CSF protein and low CSF glucose were strongly associated with antibiotic and antitubercular therapy ($p < 0.001$), reinforcing their diagnostic relevance in bacterial and tubercular meningitis and supporting observations by Davis C et al.(2020).^[14]

CONCLUSION

The present study evaluated pharmacotherapeutic approaches in meningitis and their correlation with clinical manifestations and cerebrospinal fluid (CSF)

findings in a tertiary care setting. Tubercular meningitis was the most common etiological subtype, followed closely by viral and bacterial meningitis, reflecting the endemic burden of tuberculosis in the study population. Distinct and statistically significant differences were observed in CSF parameters namely white blood cell count, protein concentration, and glucose levels across different types of meningitis, underscoring the pivotal role of CSF analysis in etiological differentiation and therapeutic decision-making.

Pharmacotherapeutic management in the study cohort was largely rational and etiology-specific. Third-generation cephalosporins and vancomycin were predominantly used in bacterial meningitis, antitubercular therapy was uniformly administered in tubercular meningitis, and acyclovir was mainly prescribed for viral meningitis, indicating good adherence to standard treatment guidelines. Adjunctive therapies such as corticosteroids and antiepileptics were more frequently used in bacterial and tubercular meningitis, correlating with greater disease severity and higher incidence of neurological complications. Significant associations between clinical features, abnormal CSF findings, and the type of pharmacotherapy further highlight the importance of integrated clinical and laboratory assessment in optimizing meningitis management. Overall, the study demonstrates that timely diagnosis supported by CSF analysis and rational pharmacotherapy tailored to etiology can contribute to improved clinical outcomes in meningitis patients.

Limitations of the Study

1. The study was conducted at a single tertiary care center, which may limit the generalizability of the findings to other healthcare settings or regions.
2. The sample size was relatively modest, and subgroup analyses for specific etiological categories may therefore have limited statistical power.
3. Microbiological confirmation of etiological agents was not available for all patients, and diagnosis was often based on clinical and CSF parameters.
4. Long-term outcomes and neurological sequelae after discharge were not assessed, restricting evaluation of the long-term impact of pharmacotherapy.
5. The study did not evaluate antimicrobial resistance patterns, which could influence therapeutic effectiveness and outcomes.

REFERENCES

1. Kumta N, Roberts JA, Lipman J, Wong WT, Joynt GM, Cotta MO. A systematic review of studies reporting antibiotic pharmacokinetic data in the cerebrospinal fluid of critically ill patients with uninflamed meninges. *Antimicrobial Agents and Chemotherapy*. 2020 Dec 16;65(1):10-128.
2. Onita T, Ikawa K, Ishihara N, Tamaki H, Yano T, Morikawa N, Naora K. Cerebrospinal pharmacokinetic analysis and pharmacodynamic evaluation of ceftriaxone in pediatric

- patients with bacterial meningitis. *Journal of Clinical Pharmacy and Therapeutics*. 2024;2024(1):4684986.
3. Maranchick NF, Alshaer MH, Smith AG, Avaliani T, Gujabidze M, Bakuradze T, Sabanadze S, Avaliani Z, Kipiani M, Peloquin CA, Kempker RR. Cerebrospinal fluid concentrations of fluoroquinolones and carbapenems in tuberculosis meningitis. *Frontiers in Pharmacology*. 2022 Dec 12;13:1048653.
 4. Collins JM, Kipiani M, Jin Y, Sharma AA, Tomalka JA, Avaliani T, Gujabidze M, Bakuradze T, Sabanadze S, Avaliani Z, Blumberg HM. Pharmacometabolomics in TB meningitis Understanding the pharmacokinetic, metabolic, and immune factors associated with anti-TB drug concentrations in cerebrospinal fluid. *PloS one*. 2025 Mar 3;20(3):e0315999.
 5. Madadi AK, Sohn MJ. Comprehensive therapeutic approaches to tuberculous meningitis: pharmacokinetics, combined dosing, and advanced intrathecal therapies. *Pharmaceutics*. 2024 Apr 14;16(4):540.
 6. Rossetyowati DA, Sari IP, Andayani TM, Nuryastuti T. Effective empiric antimicrobial therapy of bacterial meningitis and encephalitis. *PHARMACY: Jurnal Farmasi Indonesia (Pharmaceutical Journal of Indonesia)*. 2021 Dec 31;18(2):444-52.
 7. Nau R, Blei C, Eiffert H. Intrathecal antibacterial and antifungal therapies. *Clinical microbiology reviews*. 2020 Jun 17;33(3):10-128.
 8. Haddad N, Carr M, Balian S, Lannin J, Kim Y, Toth C, Jarvis J. The blood-brain barrier and pharmacokinetic/pharmacodynamic optimization of antibiotics for the treatment of central nervous system infections in adults. *Antibiotics*. 2022 Dec 19;11(12):1843.
 9. Ali M, Shoaib MH, Nesar S, Akhtar H, Shahnaz S, Khan Q, Imran J. Assessment of potential drug-related problems (PDRP) and clinical outcomes in bacterial meningitis patients admitted to tertiary care hospitals. *Plos one*. 2023 Oct 9;18(10):e0285171.
 10. Wenzler E, Adeel A, Wu T, Jurkovic M, Walder J, Ramasra E, Campion M, Cerny J, Theodoropoulos NM. Inadequate cerebrospinal fluid concentrations of available salvage agents further impedes the optimal treatment of multidrug-resistant *Enterococcus faecium* meningitis and bacteremia. *Infectious disease reports*. 2021 Sep 8;13(3):843-54.
 11. Karvouniaris M, Brotis A, Tsiakos K, Palli E, Koulenti D. Current perspectives on the diagnosis and management of healthcare-associated ventriculitis and meningitis. *Infection and Drug Resistance*. 2022 Jan 1:697-721.
 12. Yasmin M, Nutman A, Wang L, Marshall S, Chen K, Wang J, Yahav D, Lupinsky L, Hujer AM, Bhimraj A, van Duin D. Utilizing ceftazidime/avibactam therapeutic drug monitoring in the treatment of neurosurgical meningitis caused by difficult-to-treat resistant *Pseudomonas aeruginosa* and KPC-producing enterobacterales. In *Open Forum Infectious Diseases* 2023 Nov (Vol. 10, No. 11, p. ofad507). US: Oxford University Press.
 13. Teixeira DC, Lodi Jimenez AL, França TG, Rocha KO, Bentes AA, Simões e Silva AC, Oliveira Diniz LM, Maia de Castro Romanelli R. Cytokine profiles associated with clinical outcomes in pediatric patients with meningitis: a systematic review and meta-analysis. *Journal of Child Neurology*. 2025 May;40(5):383-90.
 14. Davis C, Wheat LJ, Myint T, Boulware DR, Bahr NC. Efficacy of cerebrospinal fluid beta-d-glucan diagnostic testing for fungal meningitis: a systematic review. *Journal of clinical microbiology*. 2020 Mar 25;58(4):10-128.